

Timing In Expressive Performance

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Introduction

Rhythmic timing is arguably the most essential aspect of musical performance. This research project presents an automated method for rhythmic analysis of an audio file (.wav). The analysis process is accomplished through the Matlab programming language in a series of M-Files that may be downloaded here: <http://ccrma.stanford.edu/~chanson9/151/151.html>. The end goal of this analysis is the extraction of rhythmic inflections in recorded performance. The underlying basis of the Matlab process is the work of Dan Ellis at Columbia University and his paper on Beat Tracking by Dynamic Programming (Ellis 2007 pp 5-10). My additions and alterations to his original code allow the user to run one function and receive analytical charts and information relating to the timing of a particular performance in relation to an extracted tempo. This may be used in conjunction with listening exercises to determine the rhythmic signature of a particular performance and/or performer. My hope is that this process will allow for a deeper understanding of individual rhythmic musical expression.

Matlab Methodology

The Matlab programs submitted with this paper should provide a generic framework for rhythmic analysis of a .wav file. There are six main M-Files that comprise this application. Upon the successful execution of these six m-files (using the run function), the user receives 3 main outputs: a tempo estimate, an onset strength envelope chart and a rhythmic inflection chart.

Below are details of each M-File.

1. RUN.M – This m-file is all that a user needs in order to work with this system. Assuming the rest of the m-files are present in the user's working directory, this file will take care of launching the required processes to build the analysis. The user must provide two simple arguments to the run function: a .wav filename and a performer name. The subsequent m-files are then called as needed to perform their various functions.
2. PROCESSWAV.M – This m-file is at the heart of everything that occurs in the analysis.

It takes in a file and a performer's name and outputs note onsets, beat detection and the steady state comparison at the detected tempo. In order to output this data, the file must perform the following functions:

- a. Re-sample the input signal to 8kHz to remove unwanted high frequency onset detection interference.
 - b. Take the spectrogram (STFT) of the re-sampled signal.
 - c. Convert the spectrogram to a perceptual representation by mapping 40 Mel bands via a weighted sum of spectrogram values. This is accomplished by calling the `fft2melmx` function.
 - d. Set any negative values to zero in order to obtain the correct onset strength values.
 - e. Sum the positive differences across all frequency bands.
 - f. Convolve with a Gaussian envelope to obtain onset strength envelope.
 - g. Identify song tempo through the use of `tempo2.m`.
3. `FFT2MELMX.M` – `Fft2melmx.m` is called from the `processwav` function in order to convert the normal FFT frequency bins into Mel bins. Mel frequency band representation is perceptually more accurate than a regular spectrogram. The only arguments required for this function to run is the `fft` size and sample rate. The function returns a matrix of weights that are applied to the original FFT bins for conversion.
4. `TEMPO2.M` – `Tempo2.m` is called from the `processwav` function in order to identify the tempo of the song. As a function, `tempo2` takes in an input signal, sample rate, BPM mode estimate and a BPM spread. It will then output a BPM, autocorrelation of note onsets, mel-frequency spectrogram and an onset envelope for the given input file. Information regarding this process of onset detection was found in chapter 3 of Tristan Jehan's PhD thesis [Creating Music By Listening](#) (Tristan sec. 3.4). The main function of this m-file is to perform the autocorrelation analysis as follows:
- a. Perform an autocorrelation of onset strength envelope (i.e. take the inner product of envelope with delayed versions of itself. For delays that line up many peaks, a

large correlation occurs).

- b. Window the autocorrelation at default BPM of 110 (this can be changed, but it works for most songs). The highest peak should be representative of the tempo.
5. LOCALMAX.M – Localmax.m is called from tempo2.m in order to identify the maximum peak during the autocorrelation analysis in tempo2.m.
6. CREATEFIGURE.M – This m-file is called from within run.m and will generate the charts seen as the analysis finishes processing.

These six files comprise all that is necessary to perform the rhythmic analysis of .wav files outlined in this paper. The user should be able to place these M-Files in their Matlab working directory and execute the “run” function to obtain the information outlined in this paper.

Initial Test Analysis

For my initial test analysis, I ran seven .wav files through this system and analyzed their respective outputs. Six of these .wav files were actual musical performances. One .wav file was a rigid midi interpretation of the same musical piece. The musical source material for my test analysis was Bach’s Invention #1 in C Major. I chose this piece because it is typically performed in a rather straight rhythmic manner and therefore, tempo/onset detection would be more accurate for a first test. In addition, this piece has been interpreted by many musicians, giving me a variety of recorded performance styles to work with. The subsequent page contains a chart of the musical performances chosen for this analysis.

Performer	Recording	Label	Library MCD #
MIDI	-	-	-
Glenn Gould	Bach: The Two and Three Part Inventions	Sony Classical 2006	12711
Janine Jansen	Bach: Inventions and Partita	Decca 2007	14926
Evgeni Koroliov	Inventions & Sinfonias	Hanssler Verlag 2000	6556
Wanda Landowska	Bach: The Landowska Recordings	Sony 2005	15683
Max Reger	J.S. Bach bearbeitet von Max Reger	Wergo 2000	7647
Andras Schiff	Great Pianists of the 20 th Century	Philips Classics 1999	6672V.88

Figure 1: Performance Chart

There are three main outputs from the Matlab scripts that I used extensively in my analyses of the various performances: the tempo estimate, the onset envelope chart, and the rhythmic inflection chart. The base performance with which all other performances were compared was the rigid midi interpretation, which had a tempo estimate of 86 BPM. The onset envelope chart and rhythmic inflection charts are shown below:

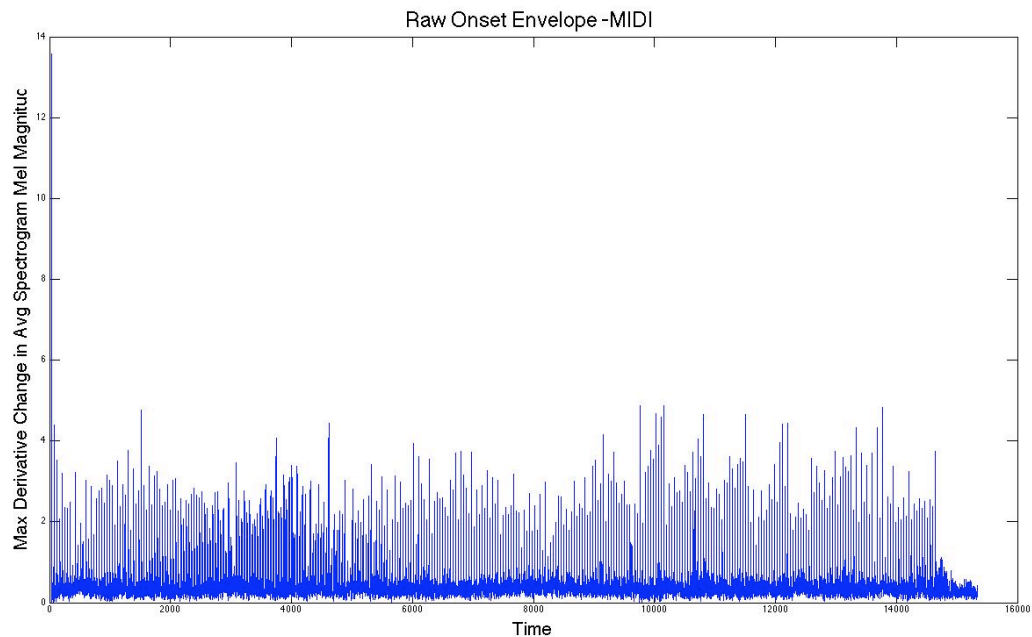


Figure 2: Raw Onset Envelope Chart - MIDI

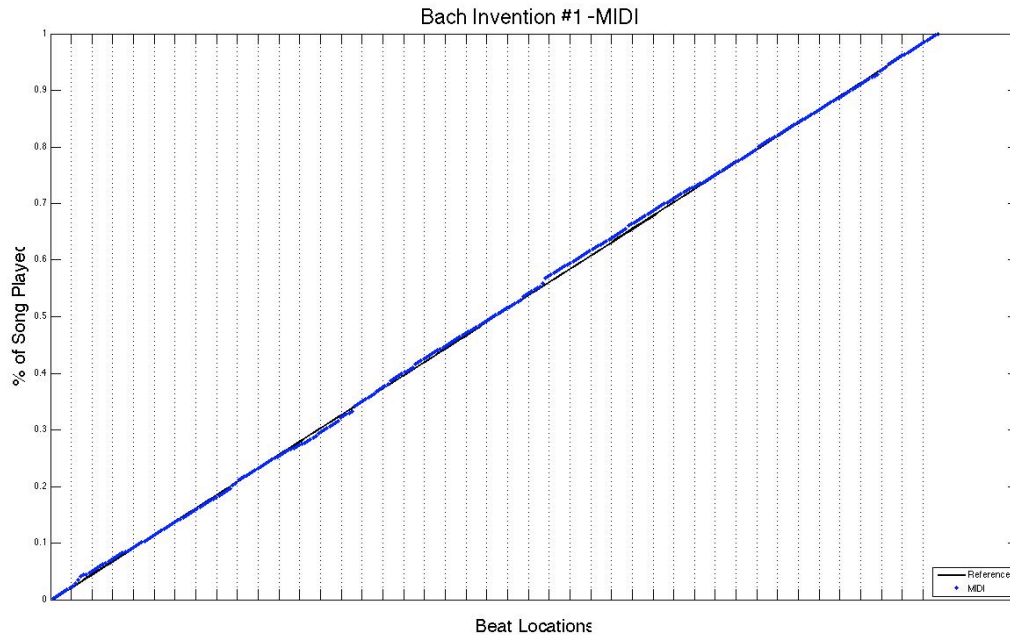


Figure 3: Rhythmic Inflection Chart - MIDI

The above charts show quite a bit of information pertaining to the midi performance of Bach's Invention #1. The raw onset envelope chart shows the individual note onsets during the course of the entire song. This is measured by the change in Mel magnitude spectrogram bands as the song progresses. The basis for this is the idea that note onsets are typically accompanied by sharp changes in the spectral content of a given sound. By identifying the maximum spectral change on a perceptual basis, you can get a decent idea of the note onsets throughout the song. The rhythmic inflection chart shows how straight the performance is throughout the analyzed recording. There is a diagonal line in black that represents a strict evenness of tempo. The blue line plotted on top of it represents the actual performance inflections contained in the recording. The vertical separation lines represent each musical beat within the piece of music¹. By quickly analyzing this chart, one can see that the midi representation of the music is almost rhythmically exact. This exact sense of timing does not typically lend itself to an expressive musical performance, hence the reason why midi representations of music are usually dull and lifeless.

¹It is of interest to note that the tempo detection is not always 100% accurate in this methodology. The major problem is the identification of tempo being twice as fast or twice as slow as the actual tempo. Because of this, the beat locations may actually show half-beats or double-beats. It is good to keep this in mind as other performances are analyzed.

The findings from the midi analysis above become interesting when we compare them with the results of analysis of the real performances. The subsequent pages show both onset envelope and rhythmic inflection charts for each of the performances I analyzed and a brief description of the conclusions drawn from each analysis.

1. Glenn Gould – Piano

Glenn Gould's performance was clean, with good note onsets and a steady rhythm. The onset envelope chart shows strong onsets and clear delineation between notes. The rhythmic inflection chart really captures the essence of Gould's performance as his inflection line is very close to that of the diagonal reference. Note that the tempo detected during analysis was twice that of the actual tempo.

Glenn Gould

Piano

Tempo Detected: 119.05

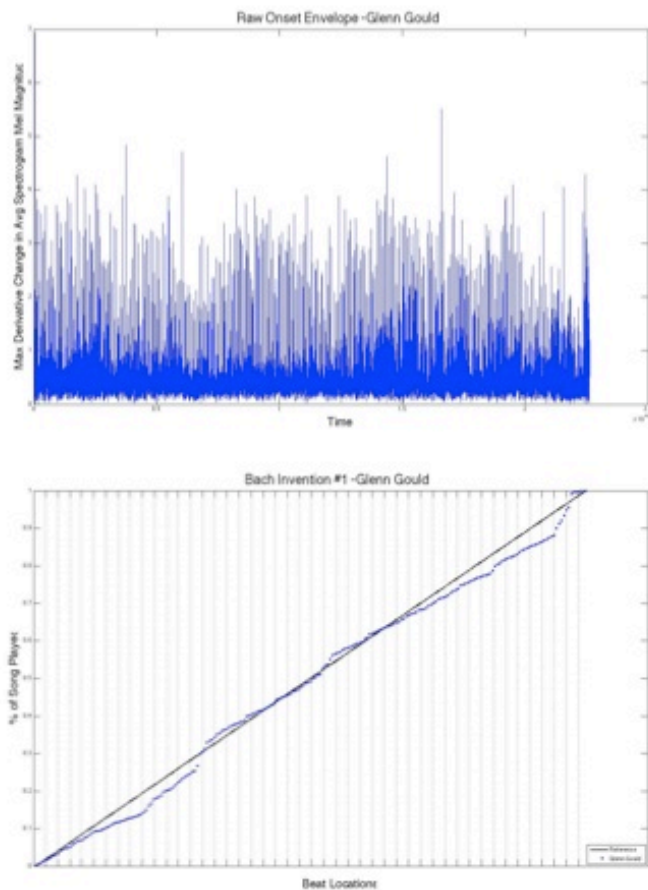


Figure 4: Glenn Gould

Janine Jansen

Violin and Viola

Tempo Detected: 83.33

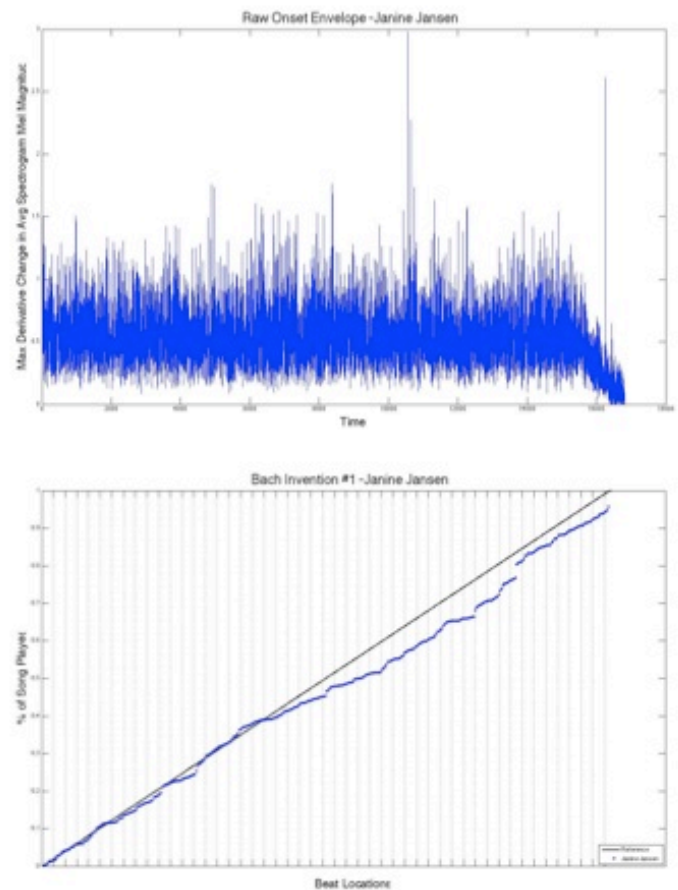


Figure 5: Janine Jansen

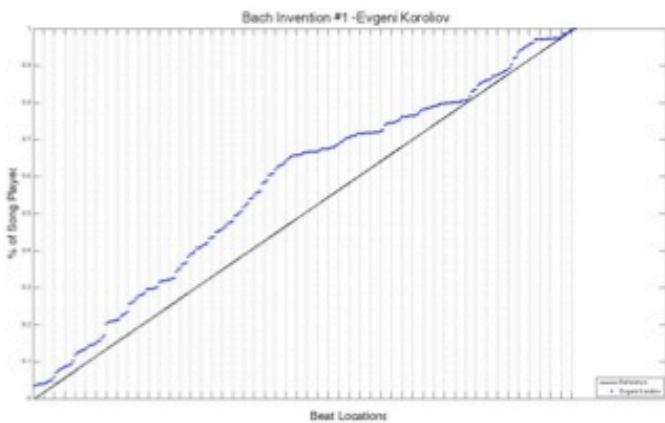
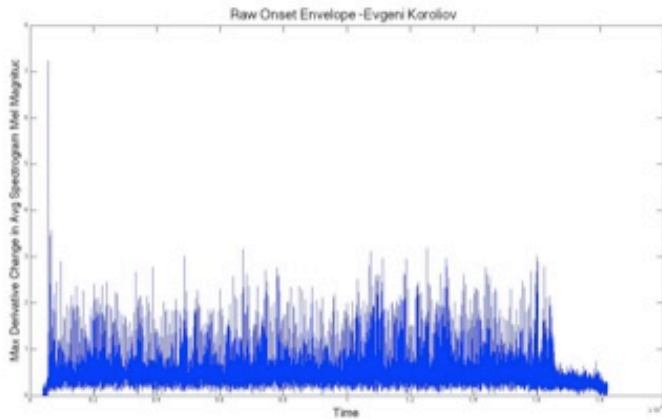
2. Janine Jansen – Violin and Viola

Jansen's rendition for violin and viola is rhythmically very expressive. I believe this is evidenced in the rhythmic inflection chart, as there is a downturn in rhythmic speed halfway through the invention. This downturn is evidenced upon listening. However, I also hear a lot of smaller rhythmic inflections throughout the performance, which are not readily apparent in the chart above. It is interesting to note the dense nature of the onset envelope. I suspect both of these issues are due to the instrumentation used in the performance.

Evgeni Koroliov

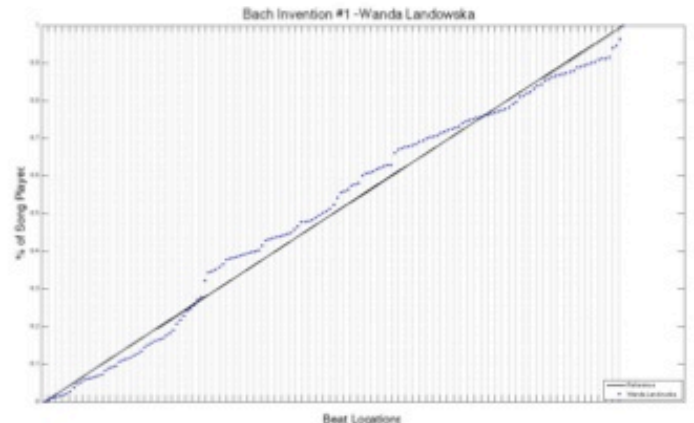
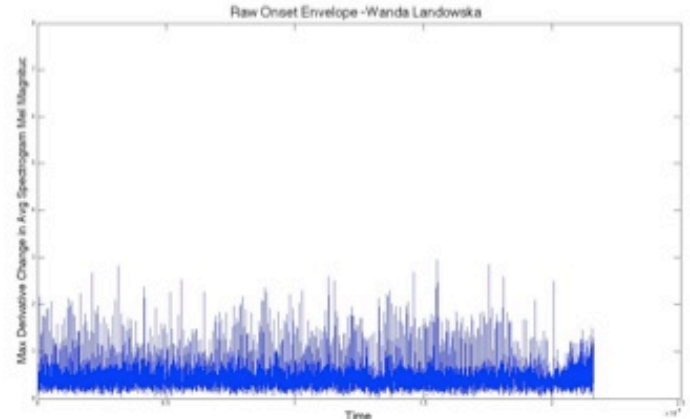
Piano

Tempo Detected: 85.23

**Figure 6: Evgeni Koroliov****Wanda Landowska**

Harpsichord

Tempo Detected: 65.22

**Figure 7: Wanda Landowska**

3. Evgeni Koroliov - Piano

Koroliov's performance is a bit more straight than the above chart eludes. However, this performance showcases some variety from the other performances I analyzed. One can even make out a bit of swing applied to the Bach's bassline in the recording. Koroliov definitely takes his rhythmic liberties, but stays fairly regular.

4. Wanda Landowska – Harpsichord

Landowska's performance is much slower and more even than most of the others. The onset detection and rhythmic inflections both seemed to work quite well, which I believe is due to the timbre of the harpsichord and the quality of the recording.

Max Reger

Organ

Tempo Detected: 41.44

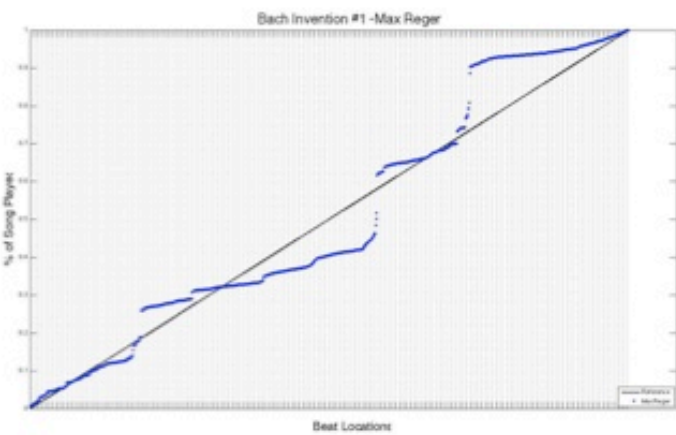
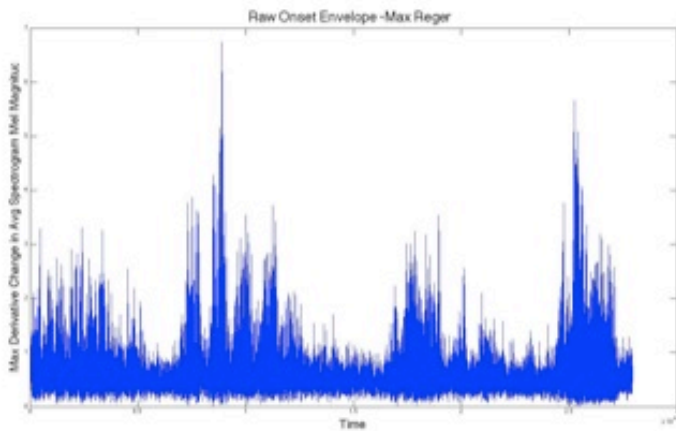


Figure 8: Max Reger

Andras Schiff

Piano

Tempo Detected: 129.31

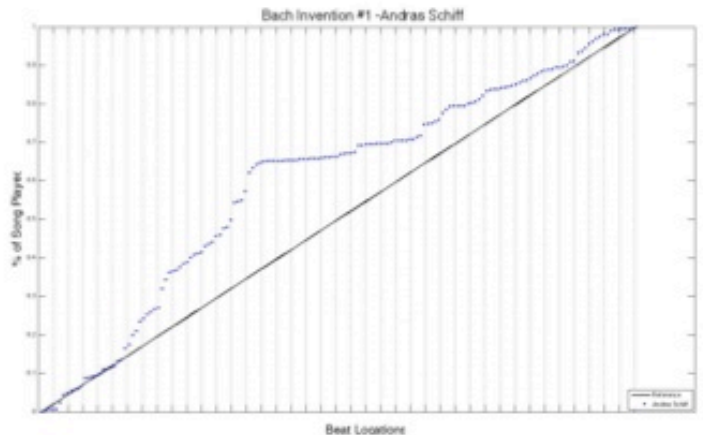
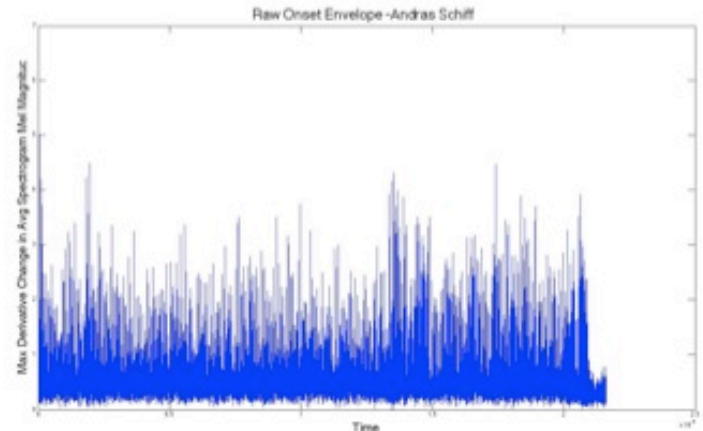


Figure 9: Andras Schiff

5. Max Reger – Organ

Certainly the most adventurous of all renditions of Bach's Invention, Max Reger takes his liberties with rhythm throughout his performance. It is evident in both of the charts above that Reger was uneven throughout the piece, however, he uses this artistically to shape Bach into a work of his own.

6. Andras Schiff – Piano

Andras Schiff provides the most heavily articulated performance of the lot. I believe this is the reason why the tempo was detected at 129.31 BPM when it is actually played around 60 BPM. The rhythmic inflection chart shows the liberties taken in this performance. Following the tempo while listening will confirm that he does speed up and slow down his performance. However, this chart may be slightly inflated due to articulations throughout the piece.

Conclusion

The findings from the initial test analysis show that the rhythmic content of a performance may be captured by automated means. Tangible results have been presented from a test scenario using actual musical performances of varied instrumentation. Further analysis of other genres of music are necessary to gain a full understanding of the extent to which this process will work for identifying the underlying rhythmic character of a performance. In the future, I would like to include functionality for the midi file itself to be imported into Matlab and analyzed without having to bounce it to audio. A direct analysis of the midi file and performance deviations can then be made by including Dan Ellis' research on aligning midi scores to music audio (Ellis 2009). That said, as a first case test scenario, this proves to be an easy to use system for identifying rhythmic fluctuation throughout a various interpretations of a piece of classical music.

References

- Ellis, D. (2007, 16 July). Beat Tracking by Dynamic Programming. Retrieved March 1, 2009 from the World Wide Web: <http://www.ee.columbia.edu/~dpwe/pubs/Ellis07-beattrack.pdf>
- Ellis, D. (2009, 26 February). Aligning Midi Scores to Music Audio. Retrieved March 1, 2009 from the World Wide Web: <http://labrosa.ee.columbia.edu/matlab/alignmidwav/#3>
- Jehan, T. (2005, 17 June). Creating Music By Listening. Retrieved March 3, 2009 from the World Wide Web: <http://web.media.mit.edu/~tristan/phd/dissertation/chapter3.html>